SCALING STUDIES OF THERMAL RADIATION FLUX FROM BURNING PROPELLANTS

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ABSTRACT

The radiant thermal flux from various masses and configurations of burning bulk gun propellants was measured at distances of 2.4 to 20 meters from the source. The propellants used consisted of small-arms propellants and large-caliber artillery propellants. The masses burned ranged from 45.4 kg. to 400 kg; the configurations included open-top fiber drums of various diameters and the original shipping containers (closed). Both internal ignition and exposure to external bonfire were included.

In the burns in the open-top drums with top ignition it was confirmed that the propagation rate through the bulk material controls the overall burning rate. Additionally this rate is essentially independent of the mass, so that the burning rate is virtually proportional to the area of the burning surface, thus validating (for masses of similar shape) the two-thirds-power-of-mass law. The data also indicate that the thermal flux can be estimated from the burning time. The inverse-square-of-distance law is found to be substantially in error at close distances. This is associated with the fact that the flame is a column rather than a "fireball". Immediate propagation of burning between containers was not observed; some forms of packaging were found to give significantly greater delay-to-ignition in an external fire than others. Approximately 20 percent of the thermochemical energy appeared as radiant heat.

INTRODUCTION

The Department of Defense Explosives Safety Board (DODESB) asked the Bureau of Mines to conduct research to establish the scaling relationships involved in the radiant heat flux from quantities of burning propellants. The results of this work are to be used to determine the appropriateness of the radiation criteria used for the classifications of materials under the U.N. scheme. Since it is not practical to actually test the burning behavior of large shipments of propellant, the determination of the hazard involved in the exposure of large masses to accidental ignition relies on the ability to extrapolate results from smaller scale tests. One of the most important hazards in the combustion of an energetic material is the radiant thermal energy emitted. It is therefore important to establish the dependence of the radiant thermal flux on the mass of propellant and the distance from the fire to personnel and property which could be injured/damaged thereby.

Six gun propellants of different physical characteristics were chosen, three of which were selected to be burned in three different quantities, in the 50 to 500 kg range, in the normal shipping package(s) including single packages and small groups of packages and in a "bulk", i.e., lightly confined, configuration up to the maximum mass, measuring the radiant heat fluxes at various distances from the propellant. This was supplemented by a few tests

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on three fine-grain propellants to determine whether there were any gross differences in behavior.

MATERIALS & EQUIPMENT

The propellants chosen in the first phase of the work were IMR 5010 powder (a small arms powder packaged in fiberboard drums), M-1 single-perforated (SP) propellant for 8" howitzer (packaged in rectangular copper cans with wooden overpacking), and M-1 multi-perforated (MP) propellant for 8" howitzer (packaged in rectangular galvanized steel cans). Approximately 1500 kg of each of these were received from Rock Island Army Ammunition Plant. For the second phase of the work it was decided to investigate the burning behavior of more fine-grained propellant powders. The propellants chosen were WC844 for 5.56 mm M-196 ball, WC846 for 7.62 mm tracer, and WC blank for .30 cal. Approximately 700 kg of each were received from Rock Island AAP.

The basic instrumentation consisted of radiometers (Thermogage model 2000-8) with sensitivities ranging from 1.5 to 25 cal/sq cm/sec/volt, a Honeywell model 1858 Visicorder with model 1883A-MPD preamplifier modules, and an NEC model APC-IV Powermate field-portable computer with a Data Translation model 2821 analog/digital converter board. Six channels of instrumentation were used. The radiometers were recalibrated by the manufacturer just prior to being used in these tests.

The quantity of IMR 5010 in the as-received packages was 45.4 kg (100 lbs). For the M-1 8" SP powder this was 49.9 kg (110 lbs) and for the M-1 8" MP propellant this was 47.7 kg (105 lbs). These quantities were used as standard increments in mass for the respective propellants. The WC844 and WC846 were received in 45.4 kg (100 lb) (net wt) fiber drums and the WC Blank propellant was received in 27.2 kg (60 lb) (net wt) cans with wood overpacking. For the last three propellants the bulk burns were conducted with a standard quantity of 100 kg (220.4 lbs).

The "bulk" configuration was an open-top fiberboard drum. The original plans were to use drums of a height-to-diameter ratio reasonably close to 1:1. For this purpose commercial fiberboard drums of 45 and 60 cm dia were obtained and cut to the appropriate height depending on the quantity and bulk density of the propellant to be burned. It was found early in the program that the burning rate and thus the heat flux is controlled by the cross-sectional surface area of the propellant, so in order to have a consistent basis for comparing different burns, most of the burns were actually done at a fixed diameter of 60 cm.

The radiometers were laid out at the burning ground at the Bureau's Lake Lynn Laboratory as shown in figure 1. The (logarithmic) increments in distance between successive radiometer stations were chosen to be ratios of approximately the cube root of 2. (A maximum of six radiometers was used in any one test.) This scheme of deployment of the radiometers represents an attempt to simultaneously view the test from widely different angles, and

obtain data at widely different distances, while staying within the physical constraints imposed by the topography of the burning ground. The radiometers were deployed with those of successively higher sensitivity at successively greater distances from the burning propellant. The distances which correspond to the radiometer locations in figure 1 are listed in table 1.

All burns were initiated with an Atlas electric match assembly in a small 0.0013 cm thick polyethylene bag containing 10 grams of FFFg black powder. All tests were video-taped. A brief summary of the 49 tests performed is shown in table 2.

DESCRIPTION OF TESTS

The initial tests (Nos. 1-6) were run using one container each of the various propellants, both in open-top fiberboard drums and in the original (closed) shipping containers. (For the closed containers two small holes just sufficient for the electric match leads were drilled in the lid of the container.)

In the first test with 45.4 kg of IMR 5010 in an open-top drum the ignitor was placed in the center of the drum. The result was that both burning and unburned propellant were violently ejected from the drum so that neither the quantity actually burned nor the location of the center of the "fireball" could be accurately determined. Thus in all subsequent tests the ignitor was just buried (approximately 2 cm deep) in the center of the top surface of the propellant.

In the initial tests with the closed shipping containers (Nos. 4-6), the result was similar to that with the central ignitor, i.e., the container burst, throwing a mixture of burning and unburned propellant (in one case more than 20 meters from the original location). Thus the attempt to burn any propellant in closed containers was abandoned, except for the UN 6(b) tests (Nos. 44 - 46) and the bonfire burns (Nos. 31 to 36 and 47 to 49) and one test (No. 14) in which a closed container was ignited next to another closed container with no ignitor, to determine whether the explosion of one container was sufficiently violent to rupture and ignite the second container (the result of this test was negative).

The early tests (Nos. 1 - 15) were run with the radiometers closely spaced, i.e., from 2.5 to 8.0 meters, in order to maximize the signal-to-noise ratio. However it was noticed in these tests that the reproducibility from one test to another was poorer than expected and that the radiant heat flux was falling off less rapidly with increasing distance than an inverse-square law would dictate. Visual observation showed that: (1) there is a tendency to throw showers of burning (and unburned) propellant from the containers, which upsets the symmetry of the experiment, and (2) the fire was not a fireball but a fire column, i.e., it approximates a line source more than a point source at close distances, and for a line source the flux should vary inversely with the first power rather than the second power of the radius. This effect is discussed

further below. Thus the remaining tests were run at larger radiometer distances of 6.4 to 20.0 meters. As will be seen, this resulted in closer conformity to the inverse-square relation.

For the bonfire burns and all the burns using the fine-grain propellants, a fixed radiometer distance of 15.0 meters was used. For the multi-package tests, the containers were tightly wired together with 12 wraps of No. 16 gauge steel wire.

The results of all the tests are shown in tables 3 to 8 for the IMR 5010, M1-8"-SP, M1-8"-MP, WC844, WC846, and WC Blank propellants, respectively. The tables show, for each mass of propellant, and each of six radiometer positions (in some cases fewer than six positions are given, either by design or through failure of the instrumentation), the instantaneous peak radiant heat flux, the maximum value of the radiant heat flux observed over any 5 second interval, and the average radiant heat flux over the duration of the burn. For each test it also shows the burn time, the total radiant heat flux that would be emitted if the average radiant heat flux seen by the radiometers (weighted by the square of their distances from the source) were emitted uniformly in every direction, and the last two quantities divided by the propellant mass. The burn times in most cases are taken from visual observation of the video tapes. In a few cases this was not practical (in one case the video camera stopped prematurely, in a few others the burning tapered off too slowly and sporadically to judge the end point). Therefore, the burn time was picked from the recorded data using the criterion that the end point was the point at which the radiant flux dropped below one-half its average value for the duration of the burn. In the initial test with the fine-grain propellants (No. 40) the very slow burning rate and low radiant flux were not anticipated so the instrumentation stopped recording before the burn was completed. The results of this test are included anyway in Table 6 for completeness. Also shown, where appropriate, are the exponents derived by a least-squares fit to the radiant heat flux vs distance.

DISCUSSION

Although the main emphasis of the work was determination of scaling relationships for the radiant thermal flux from propellants burned in the bulk mode, some other observations are worth noting. One of these is that the coarse-grain propellants burned much faster than the fine-grain ones. Another is that, in no case in the multiple package tests where one package was internally ignited did burning propagate from one package to another.

The propellant burning rate seems to be controlled by the burning rate through the bulk of the powder, the burning rate across a free surface being much faster. The burning times plotted as a function of propellant mass, for those propellants which were burned in the bulk configuration at more than one mass, are shown in figure 2. The data used to plot this figure excluded those data for which complicating factors such as internal ignition, package burns, and bonfire burns would affect the burning rate. From this figure it can be seen

that the burning time or rate is essentially linear with the mass of propellant, apart from a small offset of ca 3 sec, which presumably is the time required for the burning to become established at a constant rate. Since the cross-sectional area normal to the direction of propagation of burning is constant, the dimension in the direction of propagation is proportional to the propellant volume or mass, so that these data show that the linear propagation rate is constant, which is what would be expected.

The data in tables 3-8 can also be used to extract the total radiant thermal energy per unit mass for each propellant type. In doing this, the data taken at small distances were excluded; these data show a systematic bias toward smaller values of thermal energy. This is probably connected with the fact that, as previously pointed out, the fire is actually a tall column, so the source of much of the radiant energy is considerably above ground level, making the effective distance from the source to the radiometers larger than the distance from the propellant to the radiometers. This is discussed further below. The calculations of total radiant energy were made assuming spherical symmetry; no attempt was made to correct for the height of the fire plume since this would introduce a factor which could not be measured accurately and thereby introduce inconsistency into the results. The data extracted are given in table 9.

The heats of combustion for IMR and M1 propellants are 2.402 and 2.727 Kcal/g, respectively. When this is compared with the values obtained above, it is seen that the total radiant heat energy derived from these measurements is 18 to 21 percent of the total available thermal energy. This is on the low end of the range normally found for the fraction of total energy converted to thermal radiation (1). The most likely explanation for this is that, as pointed out above, much of the radiant energy is radiated from portions of the fire plume which are considerably above ground level and which therefore are at a greater distance from the radiometers than the burning propellant itself. Therefore, the thermal flux measured at ground level for tall plumes will thus be less than that which would be measured for a compact fireball at ground level. This is particularly true if one considers that part of the thermal energy released is due to secondary oxidation of the products in the surrounding air, a process which requires mixing of the products with the air and which is probably not complete until the products reach the top of the plume. The heat released at the base of the plume is probably that released in the monopropellant mode of burning, i.e. the heat of explosion, which for these propellants is 0.896 Kcal/g (IMR) and 0.751 Kcal/g (M1).

It is also of interest to examine the hypothesis that the thermal flux is proportional to the mass of propellant burned and inversely proportional to the burning time, as suggested by Watson (1). These data are presented in figures 3 through 5. For each test the values of the "5 - second average peak" flux were converted to an equivalent value at 15 meters using the distance scaling exponent appropriate to the data in that test. These values were then averaged over all of the radiometers used in that test. The results are the ordinates in figures 3-5. The abscissae are the mass of propellant

divided by the burning time. The data in figures 3-5, unlike figure 2, include all the tests, including the close-range data, package, and bonfire burns except for test no. 14, in which the container exploded so violently that the results are meaningless. The figures show a reasonably good fit. It is of interest to note that in figure 3 the point which lies farthest above the line is for test No. 1 (internal ignition).

The implications of this, together with the observation above, that the linear propagation velocity of the burning through the mass of propellant is constant, are that, for quantities of propellant having a given shape and bulk density but different masses, the thermal flux will be proportional to the propellant mass to the two-thirds power. The linear dimension of the body of propellant will be proportional to the cube root of the volume (and hence of the mass). Thus, the burning time will also be proportional to the cube root of the mass, and the radiant flux will be proportional to the mass divided by the burn time and thus proportional to the mass to the two-thirds power. Another way of looking at this is that the flame spreads much more rapidly across a free surface than it does through the bulk of the propellant, so that the burning rate is effectively controlled by the surface area, which for a given shape and bulk density will be proportional to the two-thirds power of the mass. Thus the results are consistent with the two-thirds power law for scaling thermal flux with burning mass provided that the shape of the burning mass considered is the same as that of the reference mass.

The inverse square law for scaling thermal flux with distance is substantially in error at close distances because the flame is in reality a column rather than a sphere. Conformity with the inverse square law improves as the distance becomes comparable to the height of the column. This is taken into account by the so-called "view factor" (2), which is a function of the height-to-diameter ratio (H/D) of the fire plume and the ratio R/D of the distance to the plume diameter. The H/D for these tests varied widely, not only from test to test, but with time in any given test. The variation ranged from a value of approximately 1 to approximately 6 in a seemingly random way. A general average value for all tests was approximately 4. The view factor varies approximately as the inverse square of R/D for values of H/D which are much less than R/D, but approximately as the inverse of R/D for values of H/D which are much greater than R/D. This is shown by the values of the "Distance scaling exponent" in tables 3 to 5, which show a systematic trend from smaller values for the close-range measurements to larger values for the longer-range measurements. At the larger ranges these results are essentially consistent with the inverse-square "law" and with similar measurements by Harmanny (3). As pointed out above, however, these results differ from Harmanny's in that they are consistent with a two-thirds-power dependence on the mass rather than the 0.82 power reported by Harmanny.

In comparison to these results, Allain(4) has measured the radiant thermal flux from large quantities of propellant in igloos. The propellant used [French LB.7T.72 (0.8)] "is similar to US M1". The quantity burned was approximately 2220 kg. In spite of the larger quantity of propellant used,

the apparent burning times recorded by Allain were relatively short and sharply peaked (15 sec total, with the flux exceeding half its maximum value for only about 6 sec). There are probably 2 reasons for this: (1) the propellant was stacked in cylindrical bags which provides many channels for the flame to spread between the bags, greatly increasing the burning area; (2) the igloo partially contains the hot gases until it ruptures, releasing them suddenly. In one of the 3 trials the igloo exploded and the thermal flux was significantly less than in the other two. If this trial is ignored, the average flux for the remaining two trials was 12.7 w/sq cm (= 3.0 cal/sq cm/sec) at a total distance of 19.2 m, and 5.8 w/sq cm (= 1.4 cal/sq cm/sec) at a total distance of 27.7 m. This is consistent with a distance-scaling exponent of 2.1. The total integrated thermal flux (at 27.7m) is approximately 1.74 billion calories. The heat of combustion of this propellant is not given, only its heat of explosion (720 cal/g). If one assumes that it is similar to that of US M1, viz 2727 cal/g, then the fraction of energy released as radiant heat is approximately 29 percent of the total available thermal energy.

The two-thirds power scaling law is used for the classification of propellants and other flammable substances according to the United Nations Recommendations. One of the aims of this project was to determine the impact of these recommendations on the classifications of substances important to the military. The criteria for Test 6(c) place limits on blast, fragmentation, and thermal effects, and in the absence of explosion, the only criterion of concern is the thermal flux produced by the bonfire. The present criterion outlined in paragraph 44.4.4 (c) of ST/SG/AC 10/11 (5) reads: if . . . "the irradiance of the burning product exceeds that of the fire by more than 4 kW/m^2 at a distance of 15 m from the edge of the stack" . . . then the product, as packaged is assigned to UN Division 1.3. For substances, the value is corrected to correspond to a mass of 100 kg net content. For bonfire tests involving net weights larger or smaller than 100 kg or for flux measurements made at distances other than 15 m, a $(\text{mass})^{2/3}/(\text{distance})^2$ scaling law is used to normalize the data. However, thermal flux values can be estimated from a knowledge of observed burning time using the equation outlined in reference (1):

$$I = \frac{C \cdot E}{4\pi R^2 t} \qquad \text{where,}$$

I = Irradiance in kw/m^2,
C = Constant,
E = Total energy content in joules,
R = Distance from fire to gauge position,
t = Observed burn time in seconds.

A more important factor is the effect of packaging on reducing the rate of fire spread in a full cargo load of material. This factor is not realistically handled in the prescription for the UN bonfire test where the

packaged test substance is completely engulfed in flames at the outset. This is an important point that bears further discussion.

Some idea of the effect of packaging on delaying the ignition of individual packages in a massive fire event can be gained from an examination of shots 34, 35, and 36, the 3-package bonfire trials. Times to ignition of the individual packages are shown in table 10. These times were estimated from TV tapes of the burns and are measured from the ignition of the fuel-oil bonfires. In tests 34 and 35 only two times are given since the third package was ejected from the bonfire and did not burn. In shot 34 the first package ignited in 125 sec followed by the ignition of the second package 12 sec later at t = 137 sec. Similar behavior was observed in shot 36 with the first ignition at t = 104 sec, the second, 15 sec later at t = 119 sec, and the third, 10 sec later at 129 sec. This indicates little difference between the level of protection provided by the fiberboard drum used for the IMR 5010 and the steel can used for the M-1 8" MP. However, in the case of the M-1 8" SP packaged in copper cans with a wood overlay (Shot 35), ignition of the first package did not occur until 331 sec after the ignition of the bonfire. The second package ignited 60 sec later at t = 391 sec. The same behavior is shown in shot 49 in which the delay to ignition for a metal can with wood overpacking was 395 sec as opposed to shots 47 and 48 (fiber drum packages) in which the delays to ignition were 60 and 110 seconds respectively. Thus the copper-wood packaging is superior to the other types in delaying ignition. From these results it is reasonable to assume that packaging would have a significant influence on the total burning time of a full cargo of similar packages and the attendant thermal radiation from the fire. The UN bonfire test 6(c) does not account for this effect and probably overestimates the thermal flux from a cargo fire. To give a concrete example, it is worthwhile to apply the criterion for UN Test 6(c) to shot 34 of this series of tests. Table 3 shows that the 5 second average peak flux from the second ignition, the most intense event, was about 7.0 at 15 m for a net mass of 45.4 kg. Using the $M^{2/3}$ scaling rule this flux level scales to 12 kW/m^2 for 100 kg which is well above the limiting criterion of 4 kW/m^2. So far there is no problem. However, if we scale this value to 10,000 kg (a typical cargo load) we obtain a flux level of 258 kW/m^2 at 15 m, enough to spontaneously ignite wood at 41.6 m (33.5 kW/m^2). In applying the $M^{2/3}$ scaling rule we assume that the 10,000 kg cargo behaves like a single big package, rather than numerous individual packages producing a random series of 7.1 kW/m^2 events, or small multiples of this value when several packages ignite spontaneously. In this case the thermal flux could be significantly lower than that predicted by the $M^{2/3}$ scaling rule used to scale results from test 6(c). Additional research is required to resolve this problem.

CONCLUSIONS

The results reported herein for burning of gun propellants in bulk are consistent with a two-thirds power dependence of the radiant thermal flux on

the propellant mass, and with an inverse-square dependence of the flux on the distance from the fire.

In multiple-package burns there is no evidence that ignition of a package directly causes ignition of an immediately adjacent package.

Propellant packages consisting of a metal can with wood overpacking provided significantly more protection (in terms of delay to ignition) against exposure to external fire.

REFERENCES

1. An Alternative to Thermal Flux Measurements in UN Test 6(c), Watson, R. W., Proceedings of the 24th Department of Defense Safety Seminar, St. Louis, MO, 8/28-30/90.

2. Fire Protection Handbook, National Fire Protection Association, Cote, A.E., ed., 16 th Edition (1986) p.21-40.

3. Thermal Radiation Flux of Fireworks, Harmanny, A., Prins Maurits Laboratorium, TNO, OECD-IGUS Report (1984).

4. Allain, L., Combustion of Gun Propellant in Igloo Thermal Flux measurements. SNPE NT No. 153/91/CRB-S/TS/NP, 12/30/91 pp 12/63-22/63.

5. United Nations Recommendations on the Transport of Dangerous Goods, Tests and Criteria, United Nations ST/SG/AC 10/11/Rev 1, Second edition 1990.

Table 1 Radiometer Distances

Radiometer Position (see Fig. #1)	Distance from Propellant (meters)
1	2.5
2	3.2
3	4.0
4	5.0
5	6.4
5A	6.4
6	8.0
7	10.0
7A	10.0
8	12.8
9	16.0
10	20.0
2A	15.0
3A	15.0
5B	15.0

Table 2. Summary of Tests

Test. No.	Propellant	Mass (kg)	Package /bulk	No. of pkgs	Radiometer dist.(m)	Comments
1	IMR	45.4	B	-	2.5 - 8.0	Central ign
2	M1-8"SP	49.9	B	-	2.5 - 8.0	
3	M1-8"MP	47.7	B	-	2.5 - 8.0	
4	IMR	47.7	P	1	2.5 - 8.0	
5	M1-8"SP	49.9	P	1	2.5 - 8.0	
6	M1-8"MP	47.7	P	1	2.5 - 8.0	
7	IMR	45.4	B	-	2.5 - 8.0	
8	M1-8"SP	49.9	B	-	2.5 - 8.0	
9	M1-8"MP	47.7	B	-	2.5 - 8.0	
10	IMR	45.4	B	-	2.5 - 8.0	
11	M1-8"SP	49.9	B	-	2.5 - 8.0	
12	M1-8"MP	47.7	B	-	2.5 - 8.0	
13	IMR	90.7	B	-	2.5 - 8.0	
14	M1-8"SP	99.8	P	2	2.5 - 8.0	
15	M1-8"SP	49.9	B	-	2.5 - 8.0	
16	M1-8"MP	47.7	B	-	6.4 - 20.0	
17	M1-8"MP	47.7	B	-	6.4 - 20.0	
18	IMR	45.4	B	-	6.4 - 20.0	
19	IMR	45.4	B	-	6.4 - 20.0	
20	M1-8"SP	49.9	B	-	6.4 - 20.0	
21	M1-8"SP	49.9	B	-	6.4 - 20.0	
22	IMR	90.7	B	-	6.4 - 20.0	
23	IMR	90.7	B	-	6.4 - 20.0	
24	M1-8"MP	95.3	B	-	6.4 - 20.0	
25	M1-8"MP	95.3	B	-	6.4 - 20.0	
26	M1-8"SP	99.8	B	-	6.4 - 20.0	
27	M1-8"SP	99.8	B	-	6.4 - 20.0	
28	IMR	181.5	B	-	15.0	
29	M1-8"SP	199.6	B	-	15.0	
30	M1-8"MP	190.6	B	-	15.0	
31	IMR	45.4	P	1	15.0	Bonfire
32	M1-8"SP	49.9	P	1	15.0	Bonfire
33	M1-8"MP	47.7	P	1	15.0	Bonfire
34	IMR	136.1	P	3	15.0	Bonfire
35	M1-8"SP	149.7	P	3	15.0	Bonfire
36	M1-8"MP	142.9	P	3	15.0	Bonfire
37	IMR	362.9	B	-	10.0 - 20.0	
38	M1-8"SP	399.2	B	-	10.0 - 20.0	
39	M1-8"MP	381.0	B	-	10.0 - 20.0	
40	WC-844	100.0	B	-	15.0	
41	WC-846	100.0	B	-	15.0	
42	WC-844	100.0	B	-	15.0	
43	WC Blank	100.0	B	-	15.0	
44	WC-844	226.8	P	5	15.0	
45	WC-846	226.8	P	5	15.0	
46	WC Blank	136.1	P	5	15.0	
47	WC-844	136.1	P	3	15.0	Bonfire
48	WC-846	136.1	P	3	15.0	Bonfire
49	WC Blank	81.6	P	3	15.0	Bonfire

Table 3
Summary of data for IMR5010

Test no 1 Mass 45.4 Kg Centr.Ign.

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
3.2	1.750	1.070	0.482
4.0	1.050	0.700	0.329
5.0	1.068	0.703	0.289
6.4	0.576	0.382	0.161
8.0	0.468	0.301	0.127

Burn time: 35.0 sec
Total radiant heat: 13.8 Megacalories
Total radiant heat/unit mass: 0.303 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.772
Distance scaling exponent=-1.47

Test no 4 Mass 45.4 Kg Packaged

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
3.2	1.400	0.767	0.348
4.0	0.900	0.450	0.154
5.0	0.780	0.432	0.191
6.4	0.372	0.184	0.075
8.0	0.234	0.118	0.049

Burn time: 42.0 sec
Total radiant heat: 19.7 Megacalories
Total radiant heat/unit mass: 0.433 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.926
Distance scaling exponent=-2.03

Test no 7 Mass 45.4 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
2.5	0.700	0.640	0.448
3.2	0.450	0.440	0.283
4.0	0.350	0.320	0.191
5.0	0.288	0.278	0.170
6.4	0.192	0.180	0.106
8.0	0.138	0.130	0.081

Burn time: 23.0 sec
Total radiant heat: 12.7 Megacalories
Total radiant heat/unit mass: 0.281 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.507
Distance scaling exponent=-1.43

Table 3 (continued)

Test no 10 Mass 45.4 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
2.5	0.600	0.600	0.435
3.2	0.550	0.530	0.339
4.0	0.450	0.430	0.287
5.0	0.336	0.319	0.218
6.4	0.240	0.230	0.146
8.0	0.168	0.154	0.099

Burn time: 17.0 sec
Total radiant heat: 13.7 Megacalories
Total radiant heat/unit mass: 0.303 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.375
Distance scaling exponent=-1.26

Test no 13 Mass 90.7 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
2.5	1.600	1.467	1.032
3.2	1.400	1.350	0.918
4.0	0.650	0.633	0.437
5.0	0.780	0.768	0.501
6.4	0.228	0.216	0.154

Burn time: 31.2 sec
Total radiant heat: 39.8 Megacalories
Total radiant heat/unit mass: 0.439 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.344
Distance scaling exponent=-1.90

Test no 18 Mass 45.4 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
8.0	0.150	0.142	0.085
10.0	0.113	0.113	0.070
12.8	0.060	0.057	0.032
16.0	0.039	0.039	0.023
20.0	0.027	0.026	0.015

Burn time: 25.0 sec
Total radiant heat: 22.1 Megacalories
Total radiant heat/unit mass: 0.488 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.551
Distance scaling exponent=-2.02

Table 3 (continued)

Test no 19 Mass 45.4 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
6.4	0.275	0.242	0.141
8.0	0.213	0.183	0.108
10.0	0.150	0.133	0.080
12.8	0.081	0.070	0.041
16.0	0.057	0.050	0.029
20.0	0.038	0.032	0.018

Burn time: 19.0 sec
Total radiant heat: 19.4 Megacalories
Total radiant heat/unit mass: 0.427 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.419
Distance scaling exponent=-1.85

Test no 22 Mass 90.7 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
6.4	0.250	0.250	0.178
8.0	0.188	0.188	0.122
10.0	0.150	0.146	0.101
12.8	0.075	0.073	0.049
16.0	0.051	0.049	0.032
20.0	0.033	0.032	0.021

Burn time: 35.0 sec
Total radiant heat: 39.6 Megacalories
Total radiant heat/unit mass: 0.437 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.386
Distance scaling exponent=-1.92

Test no 23 Mass 90.7 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
6.4	0.275	0.242	0.157
8.0	0.188	0.188	0.122
10.0	0.138	0.137	0.088
12.8	0.078	0.073	0.044
16.0	0.051	0.049	0.032
20.0	0.035	0.034	0.021

Burn time: 30.0 sec
Total radiant heat: 37.4 Megacalories
Total radiant heat/unit mass: 0.412 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.331
Distance scaling exponent=-1.83

Table 3 (continued)

Test no 28 Mass 181.4 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
15.0	0.051	0.051	0.037
15.0	0.051	0.051	0.040

Burn time: 72.0 sec
Total radiant heat: 82.6 Megacalories
Total radiant heat/unit mass: 0.455 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.397

Test no 31 Mass 45.4 Kg Pkg/bonfire

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
15.0	0.240	0.133	0.052
15.0	0.126	0.082	0.036
15.0	0.126	0.084	0.035

Burn time: 12.0 sec
Total radiant heat: 19.6 Megacalories
Total radiant heat/unit mass: 0.431 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.265

Test no 34 Mass 136.1 Kg Pkg/bonfire

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
15.0	0.288	0.166	0.072
15.0	0.294	0.162	0.081
15.0	0.324	0.174	0.086

Burn time: 16.0 sec
Total radiant heat: 67.5 Megacalories
Total radiant heat/unit mass: 0.496 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.118

Table 3 (continued)

Test no 37 Mass 362.9 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
10.0	0.114	0.114	0.077
15.0	0.060	0.060	0.040
20.0	0.033	0.033	0.021

Burn time:140.0 sec
Total radiant heat:156.9 Megacalories
Total radiant heat/unit mass: 0.432 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.386
Distance scaling exponent=-1.88

Table 4
Summary of data for M1-8-SP

Test no 2   Mass 49.9 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
3.2	0.650	0.650	0.365
4.0	0.450	0.417	0.241
5.0	0.432	0.408	0.221
6.4	0.240	0.236	0.150
8.0	0.186	0.180	0.107

Burn time: 29.0 sec
Total radiant heat: 22.3 Megacalories
Total radiant heat/unit mass: 0.447 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.581
Distance scaling exponent=-1.27

Test no 5   Mass 49.9 Kg   Packaged

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
2.5	1.300	1.140	0.665
3.2	1.350	1.070	0.659
4.0	0.700	0.570	0.352
5.0	0.972	0.710	0.381
6.4	0.384	0.329	0.170
8.0	0.312	0.268	0.145

Burn time: 23.0 sec
Total radiant heat: 20.4 Megacalories
Total radiant heat/unit mass: 0.408 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.461
Distance scaling exponent=-1.43

Test no 8   Mass 49.9 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
2.5	0.600	0.560	0.359
3.2	0.450	0.430	0.285
4.0	0.350	0.310	0.185
5.0	0.396	0.326	0.191
6.4	0.288	0.240	0.143

Burn time: 27.0 sec
Total radiant heat: 8.0 Megacalories
Total radiant heat/unit mass: 0.161 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.541
Distance scaling exponent=-0.96

Table 4 (continued)

Test no 11 Mass 49.9 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
2.5	2.000	1.900	1.226
3.2	2.250	1.950	1.242
4.0	1.100	0.940	0.584
5.0	1.716	1.428	0.875
6.4	0.528	0.420	0.261
8.0	0.420	0.331	0.197

Burn time: 15.0 sec
Total radiant heat: 29.8 Megacalories
Total radiant heat/unit mass: 0.597 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.301
Distance scaling exponent=-1.66

Test no 14 Mass 99.8 Kg Packaged

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
2.5	5.800	3.640	1.393
3.2	4.000	2.300	0.950
4.0	1.600	1.060	0.483
5.0	2.136	1.426	0.617
6.4	0.648	0.403	0.183
8.0	0.444	0.302	0.145

Burn time: 8.0 sec
Total radiant heat: 18.3 Megacalories
Total radiant heat/unit mass: 0.184 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.080
Distance scaling exponent=-1.98

Test no 15 Mass 49.9 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
2.5	1.500	1.200	0.900
3.2	1.250	0.940	0.635
4.0	0.800	0.660	0.474
5.0	0.984	0.667	0.425
6.4	0.648	0.492	0.316
8.0	0.498	0.371	0.236

Burn time: 15.0 sec
Total radiant heat: 20.8 Megacalories
Total radiant heat/unit mass: 0.417 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.301
Distance scaling exponent=-1.10

Table 4 (continued)

Test no 20 Mass 49.9 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
6.4	0.375	0.342	0.206
8.0	0.263	0.250	0.160
10.0	0.300	0.271	0.154
12.8	0.159	0.149	0.089
16.0	0.117	0.105	0.063
20.0	0.083	0.075	0.044

Burn time: 15.0 sec
Total radiant heat: 31.0 Megacalories
Total radiant heat/unit mass: 0.622 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.301
Distance scaling exponent=-1.38

Test no 21 Mass 49.9 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
6.4	0.400	0.375	0.247
8.0	0.313	0.300	0.188
10.0	0.300	0.275	0.165
12.8	0.153	0.146	0.087
16.0	0.114	0.107	0.062
20.0	0.080	0.074	0.043

Burn time: 15.0 sec
Total radiant heat: 32.4 Megacalories
Total radiant heat/unit mass: 0.649 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.301
Distance scaling exponent=-1.59

Test no 26 Mass 99.8 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
6.4	0.875	0.742	0.418
8.0	0.350	0.350	0.179
10.0	0.625	0.533	0.287
12.8	0.171	0.153	0.081
16.0	0.111	0.100	0.051
20.0	0.072	0.063	0.031

Burn time: 28.0 sec
Total radiant heat: 68.4 Megacalories
Total radiant heat/unit mass: 0.685 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.281
Distance scaling exponent=-2.25

Table 4 (continued)

Test no 27 Mass 99.8 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
6.4	0.750	0.717	0.426
8.0	0.375	0.350	0.194
10.0	0.700	0.629	0.330
12.8	0.174	0.160	0.079
16.0	0.108	0.106	0.051
20.0	0.063	0.062	0.030

Burn time: 28.0 sec
Total radiant heat: 71.8 Megacalories
Total radiant heat/unit mass: 0.719 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.281
Distance scaling exponent=-2.34

Test no 29 Mass 199.6 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
15.0	0.111	0.111	0.063
15.0	0.111	0.111	0.068

Burn time: 52.0 sec
Total radiant heat:111.6 Megacalories
Total radiant heat/unit mass: 0.559 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.261

Test no 32 Mass 49.9 Kg Pkg/bonfire

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
15.0	0.480	0.292	0.140
15.0	0.285	0.142	0.068
15.0	0.288	0.143	0.068

Burn time: 10.0 sec
Total radiant heat: 28.6 Megacalories
Total radiant heat/unit mass: 0.573 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.200

Table 4 (continued)

Test no 35 Mass 149.7 Kg Pkg/bonfire

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
15.0	0.654	0.294	0.151
15.0	0.588	0.293	0.132
15.0	0.570	0.296	0.132

Burn time: 23.0 sec
Total radiant heat:121.4 Megacalories
Total radiant heat/unit mass: 0.811 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.154

Test no 38 Mass 399.2 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
10.0	0.345	0.345	0.138
15.0	0.318	0.318	0.090
20.0	0.111	0.111	0.045

Burn time: 95.0 sec
Total radiant heat:229.2 Megacalories
Total radiant heat/unit mass: 0.574 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.238
Distance scaling exponent=-1.57

Table 5
Summary of data for M1-8-MP

Test no 3 Mass 47.6 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
3.2	1.600	1.433	0.733
4.0	1.000	0.833	0.467
5.0	1.032	0.936	0.464
6.4	0.504	0.404	0.212
8.0	0.420	0.336	0.166

Burn time: 15.0 sec
Total radiant heat: 20.8 Megacalories
Total radiant heat/unit mass: 0.436 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.315
Distance scaling exponent=-1.64

Test no 6 Mass 47.6 Kg Packaged

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
2.5	1.800	1.560	0.900
3.2	1.600	1.500	0.888
4.0	0.800	0.720	0.432
6.4	0.552	0.480	0.257
8.0	0.600	0.539	0.274

Burn time: 20.0 sec
Total radiant heat: 21.2 Megacalories
Total radiant heat/unit mass: 0.446 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.420
Distance scaling exponent=-1.20

Test no 9 Mass 47.6 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
3.2	1.400	1.300	0.710
4.0	1.200	1.070	0.580
5.0	1.008	0.905	0.481
6.4	0.660	0.600	0.316

Burn time: 12.0 sec
Total radiant heat: 19.6 Megacalories
Total radiant heat/unit mass: 0.411 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.252
Distance scaling exponent=-1.14

Table 5 (continued)

Test no 12 Mass 47.6 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
2.5	2.400	1.900	0.954
3.2	1.800	1.500	0.746
4.0	1.400	1.190	0.581
5.0	1.308	1.150	0.569
6.4	0.732	0.617	0.290
8.0	0.510	0.424	0.203

Burn time: 9.0 sec
Total radiant heat: 16.9 Megacalories
Total radiant heat/unit mass: 0.354 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.189
Distance scaling exponent=-1.31

Test no 16 Mass 47.6 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
6.4	0.500	0.455	0.287
8.0	0.475	0.430	0.265
10.0	0.325	0.303	0.186
16.0	0.156	0.137	0.080

Burn time: 13.0 sec
Total radiant heat: 27.6 Megacalories
Total radiant heat/unit mass: 0.580 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.273
Distance scaling exponent=-1.47

Test no 17 Mass 47.6 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
6.4	0.500	0.435	0.265
8.0	0.463	0.330	0.196
10.0	0.288	0.247	0.148
12.8	0.192	0.163	0.096
16.0	0.132	0.112	0.065
20.0	0.099	0.085	0.048

Burn time: 12.0 sec
Total radiant heat: 24.4 Megacalories
Total radiant heat/unit mass: 0.513 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.252
Distance scaling exponent=-1.53

Table 5 (continued)

Test no 24 Mass 95.3 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
8.0	0.738	0.663	0.352
10.0	1.275	1.103	0.551
12.8	0.348	0.328	0.169
16.0	0.240	0.215	0.110
20.0	0.155	0.136	0.070

Burn time: 15.0 sec
Total radiant heat: 69.1 Megacalories
Total radiant heat/unit mass: 0.725 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.157
Distance scaling exponent=-2.11

Test no 25 Mass 95.3 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
6.4	1.425	1.210	0.665
8.0	0.713	0.647	0.346
10.0	1.150	0.950	0.494
12.8	0.360	0.326	0.170
16.0	0.249	0.228	0.117
20.0	0.161	0.149	0.076

Burn time: 15.0 sec
Total radiant heat: 66.6 Megacalories
Total radiant heat/unit mass: 0.699 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.157
Distance scaling exponent=-1.90

Test no 30 Mass 190.5 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
15.0	0.246	0.232	0.127
15.0	0.210	0.194	0.108

Burn time: 25.0 sec
Total radiant heat: 99.7 Megacalories
Total radiant heat/unit mass: 0.523 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.131

Table 5 (continued)

Test no 33 Mass 47.6 Kg Pkg/bonfire

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
15.0	0.210	0.162	0.083
15.0	0.162	0.133	0.072
15.0	0.168	0.134	0.073

Burn time: 12.0 sec
Total radiant heat: 27.9 Megacalories
Total radiant heat/unit mass: 0.585 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.252

Test no 36 Mass 142.9 Kg Pkg/bonfire

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
15.0	0.576	0.386	0.155
15.0	0.432	0.250	0.094
15.0	0.360	0.211	0.083

Burn time: 19.5 sec
Total radiant heat:109.2 Megacalories
Total radiant heat/unit mass: 0.764 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.136

Test no 39 Mass 381.0 Kg

Distance (Meters)	Radiant heat flux(cal/sq cm/sec) Peak	5 Sec avg peak	Average
10.0	0.420	0.414	0.252
15.0	0.366	0.348	0.201
20.0	0.135	0.132	0.090

Burn time: 45.0 sec
Total radiant heat:211.6 Megacalories
Total radiant heat/unit mass: 0.555 Kilocalories/gram
Total burn time/unit mass(sec/kg): 0.118
Distance scaling exponent=-1.43

Table 6

Summary of data for WC844

Test no. 40 Mass 100.0 Kg

Distance (Meters)	Radiant heat flux (cal/sq.cm/sec) Peak	5 Sec avg peak	Average
15.0	0.062	0.026	0.014
15.0	0.052	0.021	0.009

Burn time: 62.6 sec
Total radiant heat: 20.190 Megacalories
Total radiant heat/unit mass: 0.202 kilocalories/gram
Total burn time/unit mass (sec/kg): 0.626

Test no. 42 Mass 100.0 Kg

Distance (Meters)	Radiant heat flux (cal/sq.cm/sec) Peak	5 Sec avg peak	Average
15.0	0.052	0.034	0.013
15.0	0.043	0.027	0.010

Burn time: 161.7 sec
Total radiant heat: 54.208 Megacalories
Total radiant heat/unit mass: 0.542 kilocalories/gram
Total burn time/unit mass (sec/kg): 1.617

Test no. 44 Mass 226.8 Kg Pkg

Distance (Meters)	Radiant heat flux (cal/sq.cm/sec) Peak	5 Sec avg peak	Average
15.0	0.090	0.048	0.013
15.0	0.090	0.059	0.021

Burn time: 165.3 sec
Total radiant heat: 80.912 Megacalories
Total radiant heat/unit mass: 0.357 kilocalories/gram
Total burn time/unit mass (sec/kg): 0.729

Table 6 (continued)

Test no. 47   Mass 136.1 Kg Pkg/bonfire

Distance (Meters)	Radiant heat flux (cal/sq.cm/sec) Peak	5 Sec avg peak	Average
15.0	0.268	0.123	0.065
15.0	0.267	0.140	0.083
15.0	0.253	0.123	0.074

Burn time: 65.3 sec
Total radiant heat: 136.728 Megacalories
Total radiant heat/unit mass: 1.005 kilocalories/gram
Total burn time/unit mass (sec/kg): 0.480

Table 7

Summary of data for WC846

Test no. 41 Mass 100.0 Kg

Distance (Meters)	Radiant heat flux (cal/sq.cm/sec) Peak	5 Sec avg peak	Average
15.0	0.029	0.018	0.011
15.0	0.073	0.039	0.025

Burn time: 215.0 sec
Total radiant heat: 106.975 Megacalories
Total radiant heat/unit mass: 1.070 kilocalories/gram
Total burn time/unit mass (sec/kg): 2.150

Test no. 45 Mass 226.8 Kg Pkg

Distance (Meters)	Radiant heat flux (cal/sq.cm/sec) Peak	5 Sec avg peak	Average
15.0	0.246	0.188	0.097
15.0	0.130	0.100	0.090

Burn time: 44.2 sec
Total radiant heat: 185.711 Megacalories
Total radiant heat/unit mass: 0.819 kilocalories/gram
Total burn time/unit mass (sec/kg): 0.195

Test no. 48 Mass 136.1 Kg Pkg/bonfire

Distance (Meters)	Radiant heat flux (cal/sq.cm/sec) Peak	5 Sec avg peak	Average
15.0	0.637	0.189	0.076
15.0	0.612	0.209	0.094
15.0	0.654	0.191	0.087

Burn time: 46.8 sec
Total radiant heat: 113.684 Megacalories
Total radiant heat/unit mass: 0.835 kilocalories/gram
Total burn time/unit mass (sec/kg): 0.344

Table 8

Summary of data for WC Blank

Test no. 43   Mass 100.0 Kg

Distance (Meters)	Radiant heat flux (cal/sq.cm/sec) Peak	5 Sec avg peak	Average
15.0	0.233	0.062	0.060
15.0	0.220	0.052	0.050

Burn time: 65.0 sec
Total radiant heat: 108.855 Megacalories
Total radiant heat/unit mass: 1.089 kilocalories/gram
Total burn time/unit mass (sec/kg): 0.650

Test no. 46   Mass 136.1 Kg Pkg

Distance (Meters)	Radiant heat flux (cal/sq.cm/sec) Peak	5 Sec avg peak	Average
15.0	0.364	0.091	0.032
15.0	0.351	0.081	0.042
15.0	0.437	0.097	0.032

Burn time: 21.9 sec
Total radiant heat: 21.867 Megacalories
Total radiant heat/unit mass: 0.161 kilocalories/gram
Total burn time/unit mass (sec/kg): 0.161

Test no. 49   Mass 54.4 Kg Pkg/bonfire

Distance (Meters)	Radiant heat flux (cal/sq.cm/sec) Peak	5 Sec avg peak	Average
15.0	0.553	0.136	0.093
15.0	0.604	0.131	0.091
15.0	0.490	0.119	0.076

Burn time: 13.8 sec
Total radiant heat: 33.876 Megacalories
Total radiant heat/unit mass: 0.623 kilocalories/gram
Total burn time/unit mass (sec/kg): 0.254

Table 9 - Linear burn rates and total radiant thermal energy per unit mass.

Propellant	Linear burn rate (cm/sec)	Radiant energy/mass (Kcal/g)
IMR 5010	1.12	0.433
M1-8"-SP	2.54	0.574
M1-8"-MP	4.88	0.555

Table 10 - Effect of packaging in delaying ignition

Shot No	Propellant type	Package type	Time to ignition (s) t_1	t_2	t_3
34	IMR 5010	Fiberboard drum	125	137	ejected
35	M-1 8" SP	Copper can with wood overlay	331	391	ejected
36	M-1 8" MP	Steel can	104	119	129

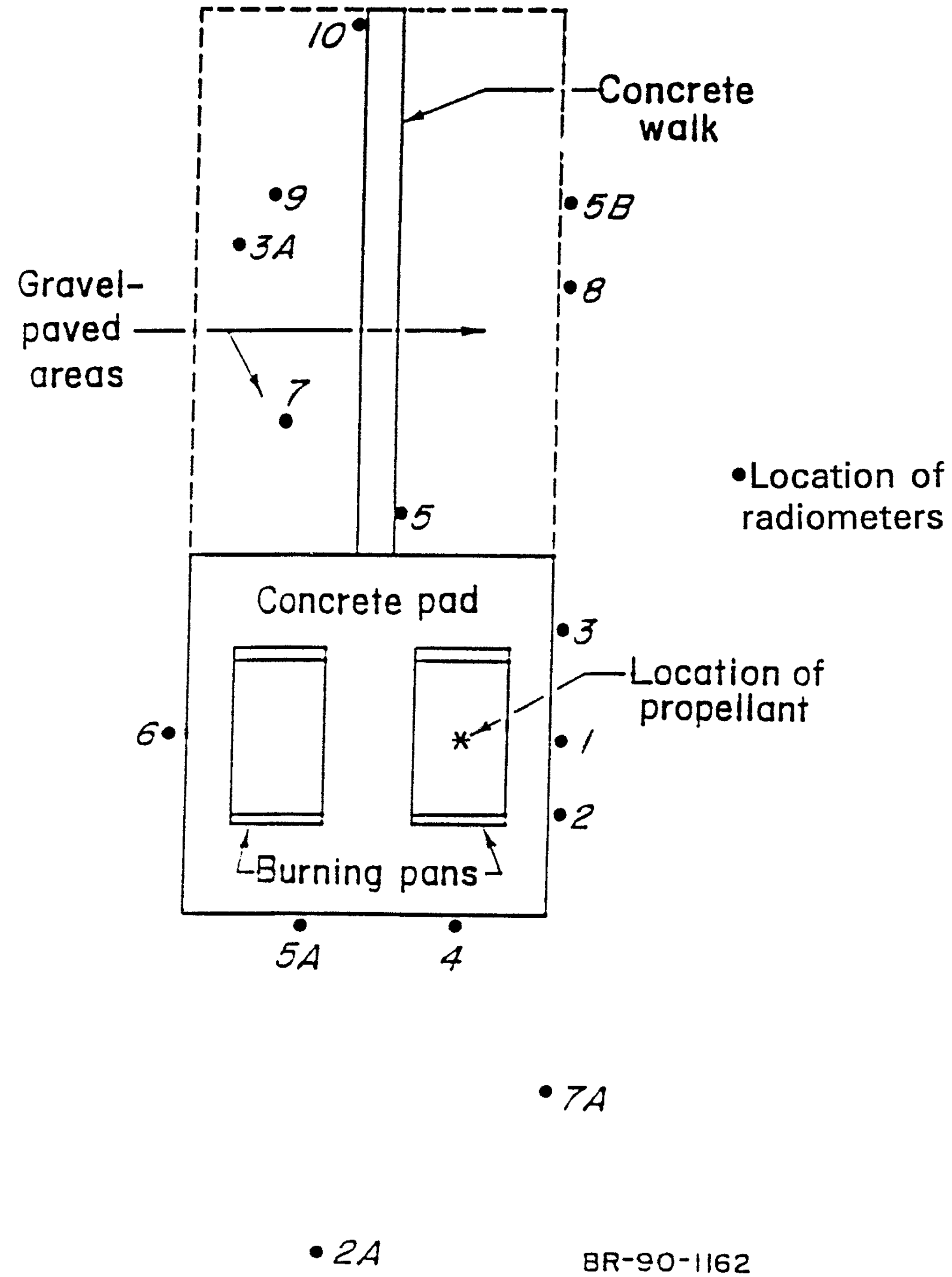


Figure 1. Layout of Radiometers at Lake Lynn Laboratory Burning Ground

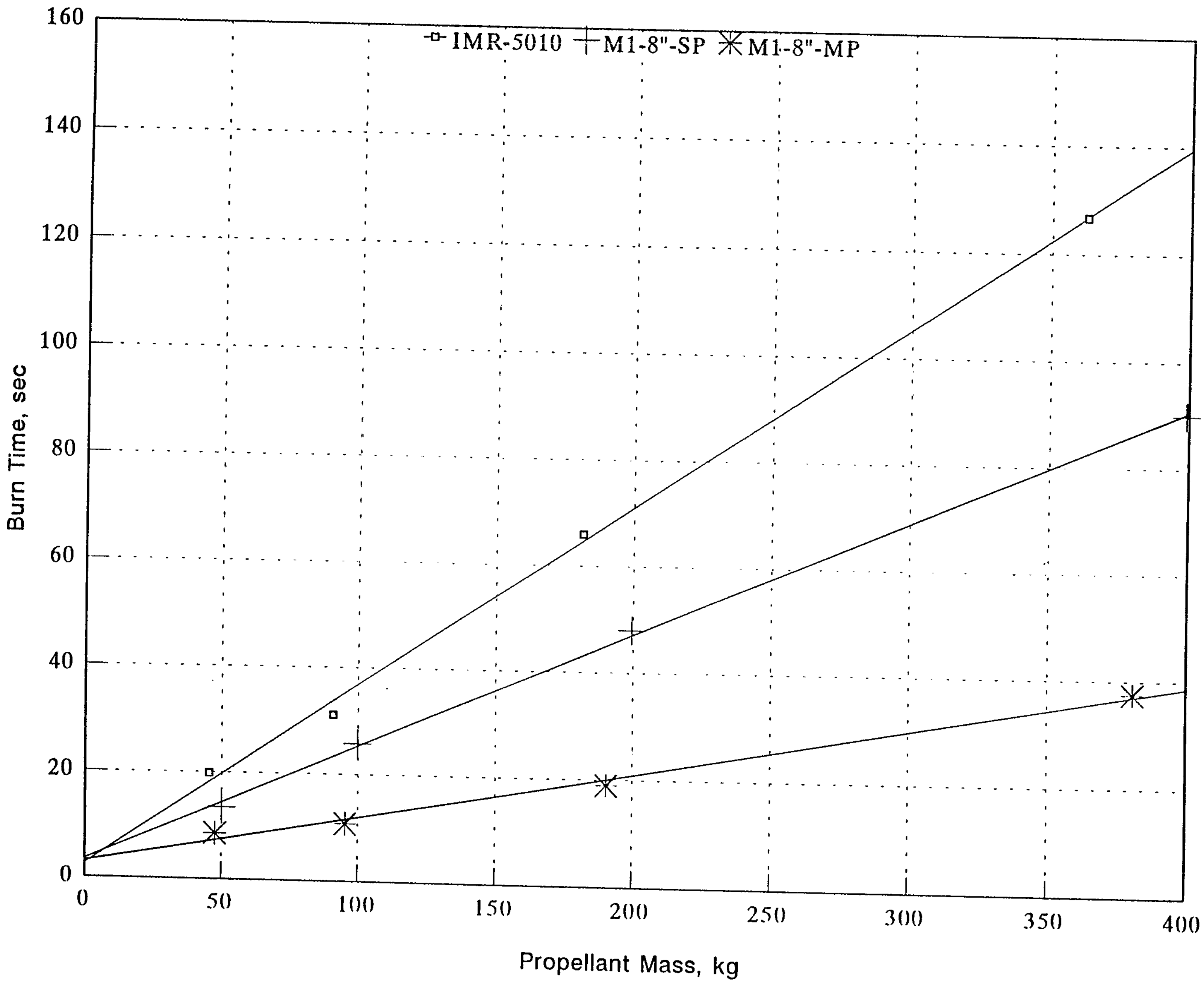
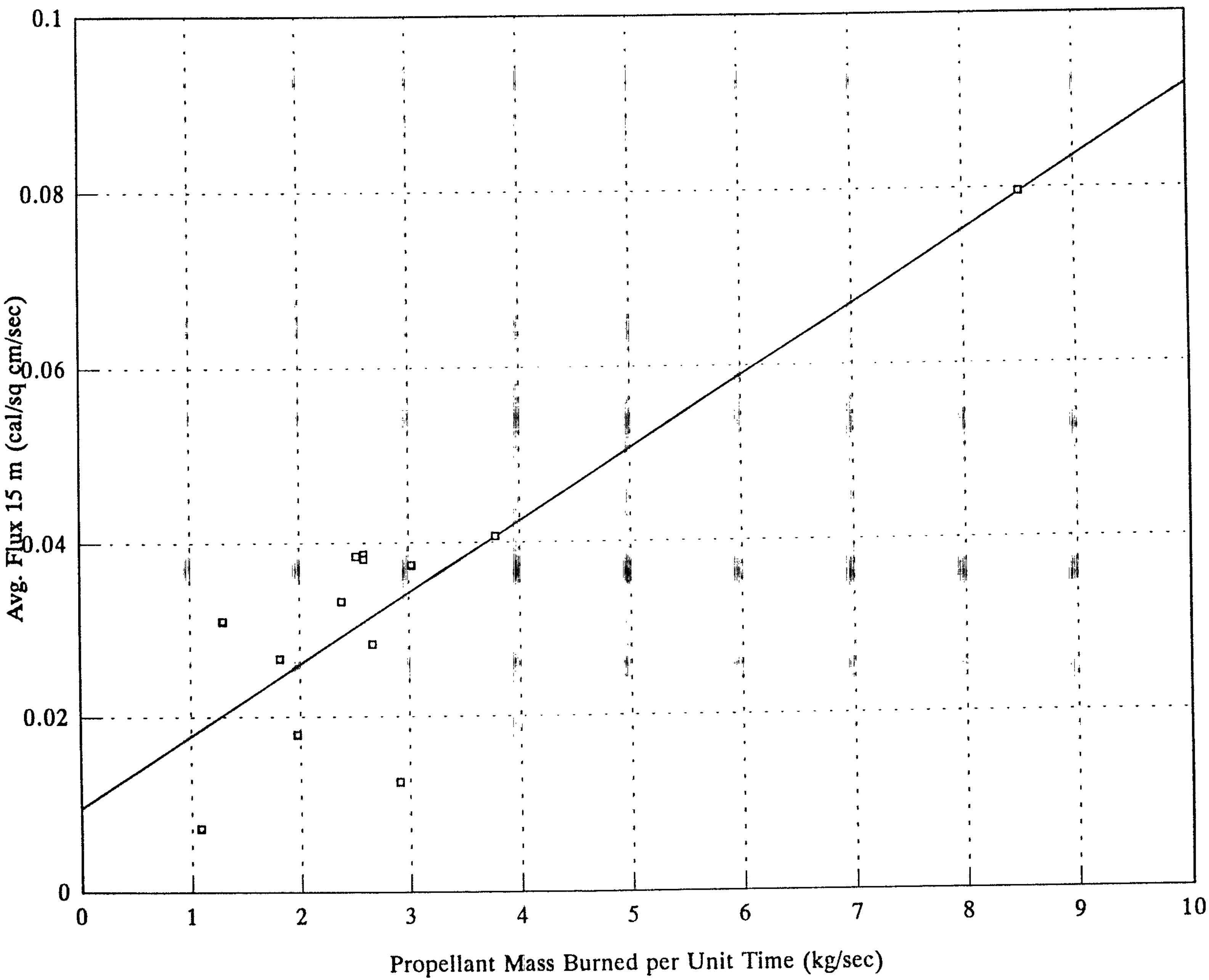


Figure 2. Burn Time vs. Propellant Mass


Avg. Flux 15 m (cal/sq cm/sec)
0.1
0.08
0.06
0.04
0.02
0
0
1
2
3
4
5
6
7
8
9
10
Propellant Mass Burned per Unit Time (kg/sec)

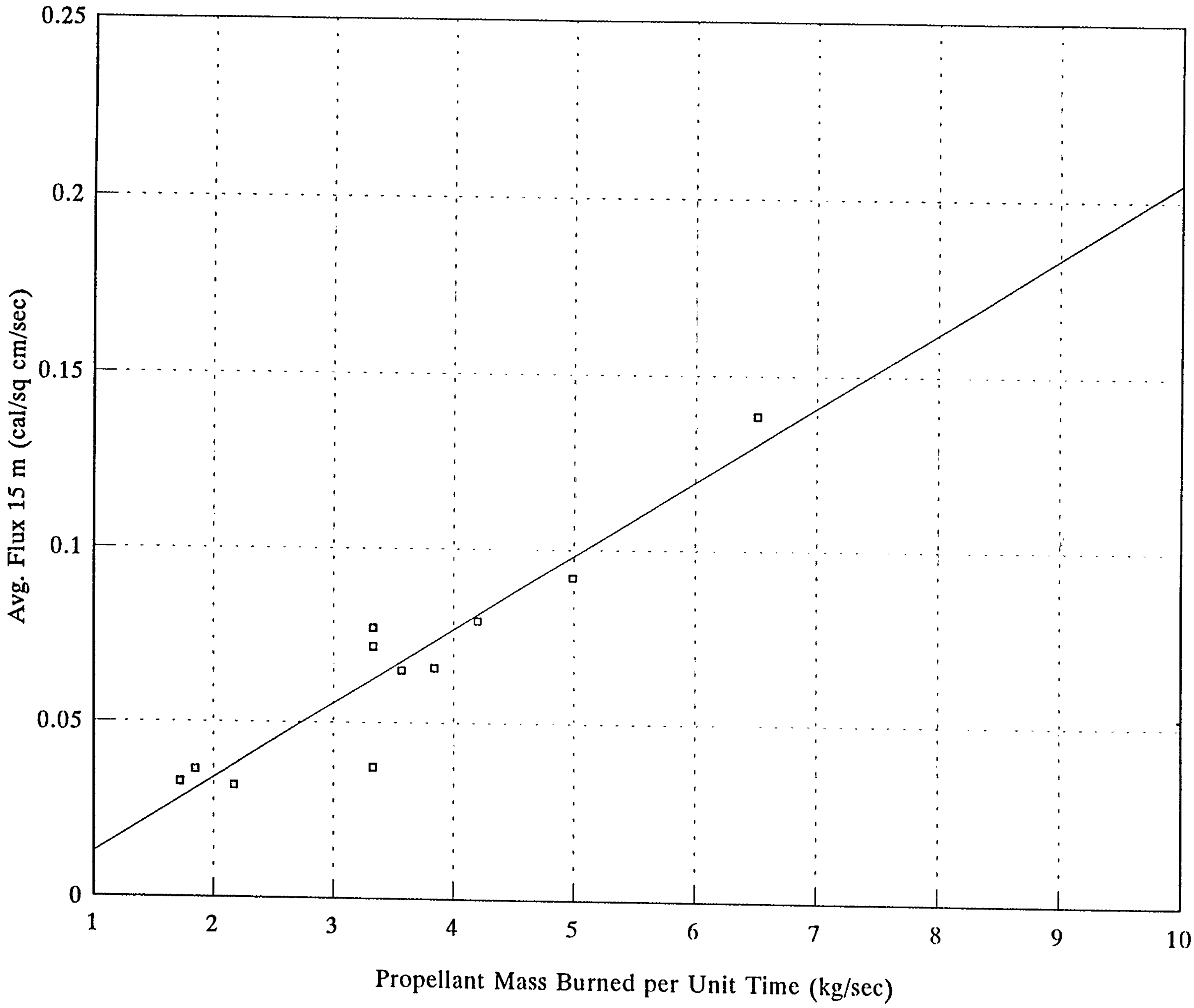
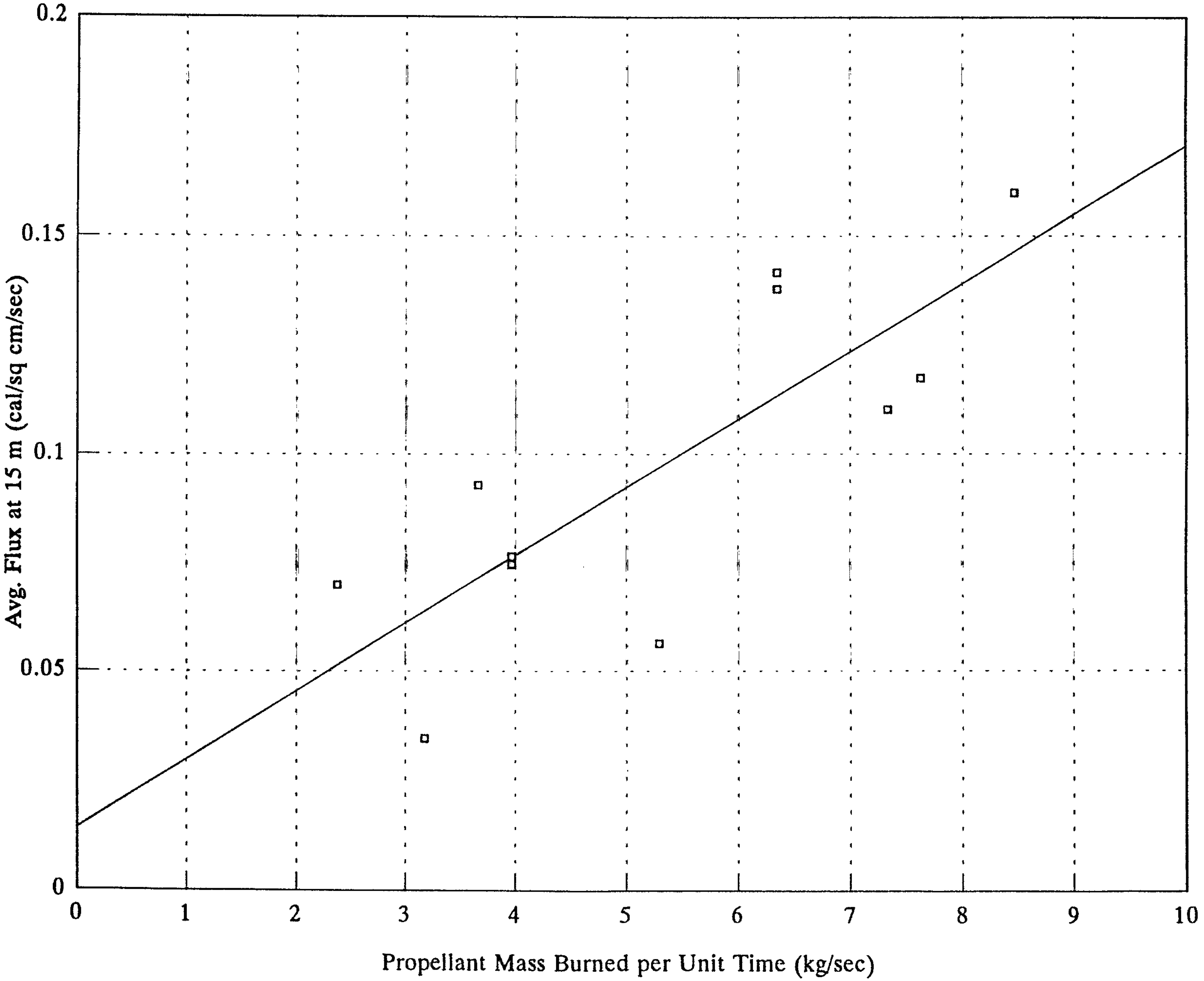


Figure 4. Average flux at 15 m vs. propellant mass burned per unit time for M1 8"SP propellant.



Avg. Flux at 15 m (cal/sq cm/sec)
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
9
10
Propellant Mass Burned per Unit Time (kg/sec)